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THE SUMMERSIDE PROJECT - AN AFBC BOILER FOR HIGH-SULPHUR COAL AND WOOD CHIPS

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PREFACE

The CFB Summerside Project, scheduled to put Canada's first fluidized-bed-fired boiler in service about the end of 1982, is attracting substantial attention both inside and outside Canada. For example, the author was invited to submit a paper describing the project to a conference on fluidized combustion being held in London, in November 1980, under the sponsorship of the British Institute of Energy. The original version, however, proved to be too long for the space allotted each paper in the conference proceedings, and substantial cuts had to be made, including all data from a pilot-scale test program with the design fuels. In order to place these data in the open literature, it was decided to publish the original version as a Divisional Report of the Energy Research Laboratories.

In preparing a project review of this nature the author is in the position of presenting information which for the most part he did not generate. It therefore seems only right that acknowledgement should be made to the designers employed by Coal Processing Consultants, Foster Wheeler Limited, Foster Wheeler Energy Corporation, and Intercontinental Engineering Ltd., who prepared the conceptual designs, as well as to the scientists of the Coal Research Establishment at Stoke Orchard, England, who carried out the pilot-scale tests.

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THE CFB SUMMERSIDE PROJECT - AN AFBC BOILER FOR HIGH-SULPHUR COAL AND WOOD CHIPS

by

F.D. Friedrich*

ABSTRACT

The paper describes two conceptual designs of coal-burning AFBC demonstration heating plant planned for Atlantic Canada. The designs were prepared under contract by two separate teams of designers of which one drew upon British, the other upon American technology.

The demonstration plant will consist of two boilers each generating 18 Mg/h of medium-pressure steam. The design fuel is high-volatile bituminous coal containing approximately 20% ash and 5% sulphur. Wood chips have been specified as a supplementary fuel to provide up to 30% of the heat input. Additional design criteria call for overbed feeding of 50 mm x 0 coal, special provisions to deal with wet and frozen coal, 4.5 to 1 turndown range, and emission limits on SO_2, NO_x and particulates.

The two conceptual boiler designs differ substantially. One proposes four identical bed sections with forced circulation bed cooling and overbed feed of coal, limestone and wood chips by means of water-cooled screw conveyors. The other design proposes spreader-firing of the fuel onto two bed sections, one being a preferential bed having only peripheral cooling, the other being a secondary bed with in-bed as well as peripheral cooling. This design uses natural circulation throughout.

Some data from pilot-scale tests with the design coal and limestone are also present.

The same design teams are now preparing detailed designs and firm price proposals, which are to be submitted in January, 1981. One system will then be selected for construction, and commissioning is expected in 1982 or 1983.

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INTRODUCTION

Fluidized-bed combustion is generally viewed as the most promising technology by which low-grade coal can be utilized with minimum environmental impact. Central heating plant applications are of particular interest because it is in this size range that the technology has reached the stage of commercial demonstration and alternative coal-burning technology is least economic. Atlantic Canada, having ample resources of high-ash, high-sulphur coal but depending on foreign sources for all its oil, represents an area where FBC technology could be applied very advantageously.

Accordingly, the Canadian departments of Energy, Mines and Resources (EMR) and National Defence (DND) have undertaken to co-sponsor an FBC boiler demonstration at Canadian Forces Base Summerside, Prince Edward Island. By means of a series of contracts, two competing teams of designers were engaged to prepare conceptual designs of a heating plant containing two 18,000-kg/h steam boilers, and are now preparing detailed designs and firm price proposals.

The present report describes the design requirements, including fuel and limestone specifications, laid down for the project. A novel feature is that the boilers must accommodate wood chips as a supplementary fuel. Results are presented of pilot-scale test work carried out by one of the contractors using the design fuels and limestone. Finally, the salient features of the two conceptual boiler designs are reviewed.

BASE HEATING REQUIREMENTS AND FUEL OPTIONS

Canadian Forces Base Summerside is located in the province of Prince Edward Island (PEI), in the Gulf of St. Lawrence. The climate is severe; daily mean temperatures are sub-zero for five months of the year and average windspeeds are approximately 25 km/h. Space heating is accordingly vital to the operation of the base. This is provided by two coal-fired steam plants which combine to supply the demand which varies from a winter peak of 25,000 kg/h to a monthly average of 2200 kg/h in August.

Plant No. 1, the larger of the two, is nearly 40 years old, presents a local pollution problem and needs to be replaced. Plant No. 2 is approximately 15 years old; it is in good mechanical condition but has inadequate capacity to meet total base requirements, and being equipped with spreader-fired dump grates without flue gas clean-up, it violates federal air quality standards.

Fuel options are limited. A natural gas pipeline eastward from central Canada is proposed but would not reach PEI for some years. Fuel oil in the Atlantic region must be imported and thus has the dual disadvantages of high cost and insecure supply. High-volatile bituminous coal is available at reasonable cost from the two neighboring provinces of Nova Scotia and New Brunswick, but quality is poor in several respects, particularly for stoker grates. The coal is strongly caking, sulphur ranges from 3 to 8%, ash content is approximately 20%, and ash softening temperatures are low. These characteristics, when coupled with stringent atmospheric emissions requirements, make the stated advantages of fluidized-bed combustion very attractive. The Department of National Defence and the Department of Energy, Mines and Resources, therefore, found little difficulty in reaching an agreement to co-sponsor a demonstration of FBC technology at CFB Summerside.

Another potential source of fuel in PEI is chipped wood waste from land clearing in connection with reforestation projects. Wood chips are limited in supply, but are considered to be sufficiently important to merit consideration as a supplementary fuel. Canadian industrial experience with fluidized-bed incinerators for wood waste indicates that co-firing of wood and coal should present no severe problems in the design of a fluidized-bed boiler.

DESIGN REQUIREMENTS

Let it be said without going into detailed explanation that a decision was reached to have the FBC boiler demonstration ultimately consist of a complete plant attached to the existing No. 2 plant, and containing two FBC boilers rated at 18,000 kg/h of steam each. Steam

conditions were chosen as 965 kPa to match the existing boilers, and a boiler turndown ration of 4.5 to 1 was selected as a design requirement.

Because PEI endures some of the highest costs for electricity in Canada, the feasibility of supplying the plant's substantial power requirements by a cogeneration scheme was reviewed, but this proved unattractive because of the low load factor. The concept of steam turbine drives on the forced draft fans had to be discarded for similar reasons.

Selection of the design coal had to take into account several facts. The existing plants burn a Nova Scotia coal containing about 3% S, which is considered to be a premium fuel in the area. One alternative is another Nova Scotia coal containing 5% S. Still another coal, strip-mined in New Brunswick, is available at a lower price, but contains 8% S. Most of the Eastern Canadian mines do not have sufficient preparation facilities to supply double-screened coal. Finally, CFB Summerside normally takes delivery of a year's coal supply during the summer months, and stockpiles it out-of-doors.

Table 1 gives data on the "design coal" selected for the project. That is, guarantees of boiler capacity, efficiency and emissions will have to be met with this coal. In addition, it is intended to carry out demonstration tests with lower-quality coal having the characteristics shown in Table 2. The design contracts require that the FBC boilers be able to burn this "demonstration fuel" but without performance guarantees. A typical analysis of the wood chips which form the "supplementary fuel" is given in Table 3. The design requirement is that the FBC boilers be able to utilize wood chips for up to 30% of the heat input at any load.

Selection of a limestone to serve as sorbent for SO_2 was simple, the Havelock quarries in New Brunswick being the only potential supplier within reasonable distance. Analytical data are given in Table 4.

The fact that the coal supply is to consist of 50 mm x 0 coal stockpiled out-of-doors and therefore delivered to the plant either wet or frozen led to stringent design requirements to ensure flow through the bunkers and handling systems. Similar requirements apply to the limestone handling systems. Another design requirement is overbed coal feed to the boiler. This is to avoid the disproportionately high cost in a small plant of the crushing and drying equipment associated with pneumatic transport.

Table 1 - Analysis and properties of the design coal:
Prince Mine, Cape Breton Development Corp.

Proximate Analysis		Dry Basis	Range
Moisture	%	0.0	0 - 10
Ash	%	19.3	16 - 22
Volatile Matter	%	33.5	
Fixed Carbon, (by diff)	%	47.2	
		100.0	

Ultimate Analysis		Dry Basis	Range
Carbon	%	64.2	
Hydrogen	%	4.0	
Sulphur	%	5.5	5 - 6
Nitrogen	%	1.0	
Ash	%	19.3	16 - 22
Oxygen (by diff)	%	6.0	
		100.0	

Calorific Value		
MJ/kg, gross	26.7	23.2 - 27.7
Btu/lb, gross	11,500	9,970 - 11,900

Ash Fusion Temperatures	Reducing	Range
Initial	1175°C (2150°F)	1100 - 1200°C
Softening, spherical	1305°C (2380°F)	
Softening, hemispherical	1355°C (2470°F)	1140 - 1375°C
Fluid	1375°C (2510°F)	1200 - 1400°C

Ash Analyses, (Typical)

SiO_2	%	39.7	CaO	%	1.0
Al_2O_3	%	23.5	MgO	%	0.5
Fe_2O_3	%	27.0	SO_3	%	0.7
TiO_2	%	1.2	Na_2O	%	2.7
P_2O_5	%	0.7	K_2O	%	2.3

Size Consist: 50 mm (2 in.) x 0 with maximum of 20% less than 0.6 mm (28 mesh).

Table 2 - Analysis and properties of the demonstration fuel (low grade coal and washery rejects)

Ash	%	40 max
Moisture	%	12 max
Sulphur	%	9 max

Calorific Value

MJ/kg, gross	20.2
Btu/lb, gross	8700

Ash Fusion Temperature

Initial 1000°C (1832°F) min

Size Consist: 50 mm (2 in.) x 0 with maximum of 40% less than 0.6 mm (28 mesh)

Table 3 - Analysis and properties of the supplementary fuel (wood chips)

Ultimate Analysis		Dry Basis	Range
Carbon	%	49.5	
Hydrogen	%	6.0	
Oxygen	%	42.0	
Nitrogen	%	1.0	
Ash	%	1.5	0.5 - 3.0
Moisture	%	0.0	30 - 60
		100.0	

Calorific Value

MJ/kg, gross	20.2	8.1 - 14.2
Btu/lb, gross	8700	3480 - 6090

Size Consist: 25 mm (1 in.) x 0 but including twigs up to 50 cm (20 in.) long
Handling equipment must be designed to cope.

Table 4 - Analysis of the design limestone:
Havelock Lime Works Ltd., Havelock, New Brunswick

		As Element, %	As Oxide, %
Loss on Ignition at 1800°F		42.60	42.60
Si	(SiO_2)	0.63	1.35
Al	(Al_2O_3)	0.08	0.15
Fe	(Fe_2O_3)	0.12	0.17
Ca	(CaO)	39.52	55.33
Mg	(MgO)	0.41	0.68
S		<0.01	
	Total	83.37	100.28

Est.	Ca present as $CaO + Ca(OH)_2$:	0.05%
Est.	Mg present as $MgO + Mg(OH)_2$:	0.01%
Est.	Ca present as $CaSO_4$, assuming all S present as $CaSO_4$:	0.01%
	$CaCO_3$:	>98%

Design requirements relating to boiler efficiency are:

1) 80% efficiency minimum, measured according to the ASME Short Form Test based on the design coal at 5% moisture, over the load range of 50% to 100% MCR, and

2) stack temperature not to exceed 175°C.

The emission requirements are those set by Environment Canada for federal facilities burning coal. They are:

SO_2	2.96 kg/10^6 kcal heat input (1.64 lb/10^6 Btu heat input)
Particulates:	0.36 kg/10^6 kcal heat input (0.2 lb/10^6 Btu heat input)
Visible Emissions:	Opacity of gases emitted to ambient not to exceed 5%

PROJECT ORGANIZATION

Design requirements having been set, as indicated in the foregoing section, the demonstration project was launched by inviting proposals to prepare a conceptual boiler design. An additional requirement was that the boiler be available from a Canadian manufacturer. At the same time the project management structure was put in place and the project was organized into six phases as follows:

	Phase	Completion Date
1.	Conceptual Boiler Design	December 1978
2.	Conceptual Plant Design	December 1979
3.	Detailed Design and Tender	January 1981
4.	Construction, Plant with 1 Boiler	December 1982
5.	Testing and Demonstration Program	March 1984
6.	Tendering and Installation of Second Boiler	December 1985

Seven proposals for boiler design were received, six of them offering American technology, one offering British technology. Careful consideration led to the decision to issue two parallel sets of contracts for Phases 1, 2 and 3, one to the agency offering British technology, the other to one of the agencies offering American technology. This was seen to have the following important benefits:

1. The likelihood of selecting the best available technology is improved.
2. Two Canadian manufacturers are brought to the point of being able to offer fluidized-bed boilers.
3. A strong element of competition is maintained, which can be expected to affect the tender prices submitted at the end of Phase 3.

Accordingly, two contracts for Phase 1 (Conceptual Boiler Design) were issued. One was awarded to a team consisting of Intercontinental Engineering Ltd (Integ), which is a Canadian consulting firm, and Coal Processing Consultants (CPC), the well-known UK firm jointly owned by Babcock UK and the National Coal Board. They produced a design based on UK

technology. The other contract was awarded to Foster Wheeler Limited, the Canadian subsidiary of Foster Wheeler Energy Corporation. They produced a design similar to the FBC boiler installed at Georgetown University in 1979. The two designs are described in detail later.

The same contractors were subsequently issued contracts for Phase 2 (Conceptual Plant Design). For this work Foster Wheeler Limited engaged the services of Montreal Engineering Co. Ltd., a consulting firm prominent in power-plant design.

Phase 3 is now in progress, and consists of detailed design and firm price proposal to build a turnkey plant. To clearly identify responsibility for boiler performance, it was desired to have the boiler manufacturer assume the role of prime contractor. Neither Integ nor CPC have manufacturing facilities, but this problem was resolved when a Canadian firm, Dominion Bridge Co. Ltd., was licenced by Babcock Contractors Inc. to build boilers according to the Babcock-CPC design. Thus, the Phase 3 contracts were issued in February 1980 to Dominion Bridge Co. Ltd. and Foster Wheeler Limited. January 5, 1981 has been selected as the tendering date.

Detailed selection criteria have been developed which together with price will form the basis for awarding the Phase 4 contract to construct the plant with one boiler. Allowing two months for the selection process and approximately twenty months for construction, Canada's first fluidized-bed boiler should be ready for service at the beginning of 1983.

After completion of boiler acceptance tests to prove that the specified requirements for capacity, efficiency and emissions control have been met, it is proposed to undertake a comprehensive demonstration program. This will likely be carried out by means of a contract to the boiler manufacturer. A major objective of this program is to demonstrate the long-term performance of the boiler with the design coal and limestone. Other objectives are to assess load pick-up and shedding capabilities, determine the maximum extent to which wood chips can be fired, and measure boiler performance in terms of capacity, efficiency and emissions, when burning high-sulphur, high-ash coals of the quality indicated in Table 2. Since the boiler can only be operated when there is a demand for steam, the demonstration program probably will not be completed until 1984. Whether the second boiler required to complete the heating plant will be a fluidized bed will depend upon the results of the demonstration program.

PILOT-SCALE TEST WORK

Both contractors were given the opportunity to include pilot-scale tests in the scope of the conceptual design contracts. Foster Wheeler Limited chose to leave this until just prior to commencing detailed design, and results were not available at the time of writing (April 1980). The Integ-CPC team carried out test work in 1978, as described in the following, using the 0.3 m x 0.3 m pilot fluidized bed at the Coal Research Establishment (CRE), Stoke Orchard. For the tests EMR supplied 800 kg of design coal (Devco-Nova Scotia), 350 kg of the design limestone (Havelock-New Brunswick), and 35 kg of high-sulphur demonstration coal (Minto-New Brunswick), all shipped via air freight!

TEST PROGRAM OBJECTIVES

Simply stated, the objectives were to obtain sufficient data on the performance of the test materials to provide a rational basis for the boiler design and to identify potential sources of difficulty. Specific areas addressed were:

- combustion performance of the two coals
- effects of coarse coal feed, ash characteristics and limestone characteristics on bed inventory trends
- performance of the design limestone as a sulphur sorbent, relative to a British limestone of known characteristics.

TEST PROGRAM

Five combustion tests were carried out, using the 0.3 m x 0.3 m CRE FB Combustor. Test parameters are given in Table 5, and specific objectives are summarized as follows:

Test No. 1 Devco coal, overbed feed, sand bed, no limestone, to obtain baseline SO_2 emissions and bed inventory trends.

Test No. 2 Devco coal, overbed feed, Penrith, UK, limestone, underbed feed, -1.68 mm to determine, with a known limestone, the effect of overbed coal feed on SO_2 emissions.

Test No. 3 Devco coal, overbed feed, Havelock limestone, underbed feed, -1.68 mm to determine bed inventory trends and SO_2 reduction with the design limestone.

Test No. 4 Devco coal, overbed feed, Havelock limestone, overbed feed, -4.8 mm to determine bed inventory trends and SO_2 reduction when the design limestone is fed over the bed in a coarse size.

Test No. 5 Minto coal, overbed feed, Havelock limestone, underbed feed, -1.68 mm to determine SO_2 reduction with the design limestone and the high-sulphur demonstration coal.

Table 5 - Operating conditions in the CRE tests

Constant Parameters

Coal Size	0-13 mm
Fluidizing Velocity	1.2 m/s
Initial Bed Material	Fresh Sand
Initial Bed Particle Size	0.5 - 0.6 mm
Bed Depth	0.52 m
Excess Air Level	20-30%
Bed Temperature	850°C
Fly Ash Recycle	None

Variable Parameters

Test No.	1	2	3	4	5
Coal Type	Devco	Devco	Devco	Devco	Minto
Limestone Type	None	Penrith, UK	Havelock	Havelock	Havelock
Size (mm)	-	-1.68	-1.68	-4.8	-1.68
Feeding	-	Underbed	Underbed	Overbed	Underbed

RESULTS AND CONCLUSIONS

Tables 6 and 7 give chemical and size analyses respectively of the design coal (Devco) and the demonstration coal (Minto) fired in the tests at CRE. Table 8 gives similar information for the design limestone (Havelock) and the British limestone (Penrith) used as a reference. The test results are summarized in Table 9.

In addition to the combustion tests, CRE carried out degradability tests with ash from both coals and with the Havelock limestone, according to an empirical method developed at CRE. The results indicated that the Devco coal and the Havelock limestone are fairly friable; therefore a high rate of elutriation is to be expected. This was confirmed in the combustion tests; only small amounts of material were extracted from the bed in order to maintain the desired level. The Minto ash was found to be very friable, but bed level can be expected to be maintained because of the high rate of limestone addition required.

Other salient conclusions are:

- High rates of limestone addition are required to meet the SO_2 emission limits. For the Devco coal at 5.3% S, limestone requirement is approximately 50 wt % of the coal feed, and for the Minto coal at 7.0% S, limestone requirement is approximately 100 wt % of the coal feed. The corresponding Ca/S ratios are 3.5:1 and 4.9:1.
- Havelock limestone is a moderately good sulphur sorbent.
- Sulphur control is better with underbed feed Of -1.68 mm limestone than with overbed feed of -4.8 mm limestone.
- The low ash fusion temperatures do not appear to present any difficulties.
- Unburnt carbon, calculated as a percentage of total carbon output, ranged from 4% to 6% without recycle.
- Tests of approximately 12 h duration with Devco coal and Havelock limestone indicated modest gains in bed inventory and no deterioration of fluidization due to accumulation of large particles.

Table 6 - Chemical analyses of the coals fired in the CRE tests

Coal		Devco	Minto
Proximate Analysis			
Total Moisture	% as fired	5.8	1.0
Ash	% as fired	18.1	15.6
Volatile Matter	% daf*	40.5	40.4
Ultimate Analysis			
Carbon	% dry basis	65.1	70.0
Hydrogen	% dry basis	4.1	4.4
Oxygen	% dry basis	7.5	3.3
Nitrogen	% dry basis	1.25	0.88
Sulphur Total	% dry basis	5.34	7.00
Sulphur Pyritic	% dry basis	3.81	5.14
Sulphur Sulphatic	% dry basis	0.13	0.07
Chlorine	% dry basis	0.05	0.05
Carbon Dioxide	% dry basis	0.06	0.18
Ash Analysis			
CaO	% on ash	0.80	2.90
MgO	% on ash	0.80	0.55
Na_2O	% on ash	0.78	0.18
K_2O	% on ash	2.40	1.60
Fe_2O_3	% on ash	27.7	43.2
Al_2O_3	% on ash	25.4	15.6
SiO_2	% on ash	40.5	33.5
Heating Value	kJ/kg daf*	33100	35580
Swelling Number		6	7.5
Hardgrove Index		63	68
Ash Fusion			
(50% CO_2/50% H_2)			
Deformation Temp, °C		1100	1070
Hemisphere Temp, °C		1140	1080
Flow Temp, °C		1200	1200

*dry, ash free

- Overbed feeding of -13 mm coal seems to present no difficulties.

Table 7 - Size analyses of the coals fired in the CRE tests

Size mm	Test Number 1, 3, 4	2	6
	Undersize, wt %		
12.7	100	99.4	99.1
9.53	93.2	90.9	79.1
6.35	79.1	64.7	43.7
3.18	42.1	46.8	23.4
1.70	22.7	31.7	12.5
0.50	7.1	13.5	4.7
0.25	3.4	7.3	2.4
0.125	2.0	4.3	1.3
0.063	0.8	2.5	0.7

THE CONCEPTUAL BOILER DESIGNS

THE FOSTER WHEELER DESIGN

A Boiler and Combustion Chamber

The Foster Wheeler conceptual design calls for a two-drum water-tube steam generator utilizing natural circulation throughout. Overall dimensions are approximately 11.3 m high x 3.7 m wide and 5.2 m deep; it can therefore be shop-fabricated ans shipped by rail on a large, depressed flat-car. A section side elevation is shown in Figure 1.

Table 8 - Chemical and size analyses of the limestones used in the CRE tests

		Havelock	Penrith
Chemical Analysis			
Moisture	%	0.1	0.1
Loss on Ignition	% (850°C)	37.6 (950°C - 43.2)	42.8
CaO	%	54.7	54.2
MgO	%	0.14	0.4
Na_2O	%	0.05	0.16
K_2O	%	0.02	0.02
Fe_2O_3	%	0.11	0.31
Al_2O_3	%	0.3	0.3
SiO_2	%	1.2	0.8
CO_2	%	43.1	43.4
Sulphur	%	0.2	0.03

Size analysis % wt undersize mm	As Received	Test No. 3	4	5	2
25.4	100				
19.0	70.2				
12.7	21.4				
6.35	4.3		100		
3.18	1.8	100	74.6		100
1.70	-	99.7	48.0	100	97.8
.50		52.5	24.1	65.5	56.3
.25		36.5	18.4	51.1	28.7
0.125		27.0	14.9	41.5	10.5
.063		20.8	12.3	31.7	5.4
Mean Particle Size mm		0.117	0.207	0.082	0.231

Table 9 - Results of CRE tests

Test No.	1	2	3	4	5
Coal Type Limestone Type	Devco None	Devco Penrith, UK	Devco Havelock	Devco Havelock	Minto Havelock
Input kg/h					
Coal	11.7	11.3	11.3	12.4	11.0
Limestone	0	6.5	6.3	6.3	12.0
Air	129.5	129.8	128.9	129.3	129.5
Nitrogen	12.6	12.7	12.5	12.6	12.7
Output kg/h					
From Bed	0	0.7	1.6	2.2	0
From Cyclone	2.2	6.0	5.2	4.9	8.3
Particulates	0.2	0.3	0.4	0.1	0.7
Mean Gas Analysis					
O_2 Vol % dry (1)	4.6	4.2	4.2	4.2	2.9
O_2 Vol % dry (2)	5.2	4.7	4.5	4.4	3.4
CO_2 Vol % dry (2)	13.5	17.0	16.0	16.8	18.4
CO Vol % dry (2)	0	0.1	0.1	0.1	0.2
CH_4 Vol % dry (2)	0	0	0	0	0
SO_2 vppm wet	3700	500	490	970	440
NH_3 vppm wet	1.4	6.2	4.9	0.3	5.3
HCl vppm wet	33.1	18.9	22.4	38.8	9.6
Excess Air	32.2	37.4	36.4	24.8	21.2
Unburnt Carbon Loss	6.0	4.4	4.0	4.9	5.5
Sulphur Retention	2.5	87.0	86.4	76.3	92.0
Sulphur reduction	0	87.0	86.6	74.0	88.9
Ca/S mol Ratio	0	3.5	3.5	3.2	4.9

Notes: (1) O_2 continuous record by Kent analyzer

(2) Spot check by chromatographic analyzer

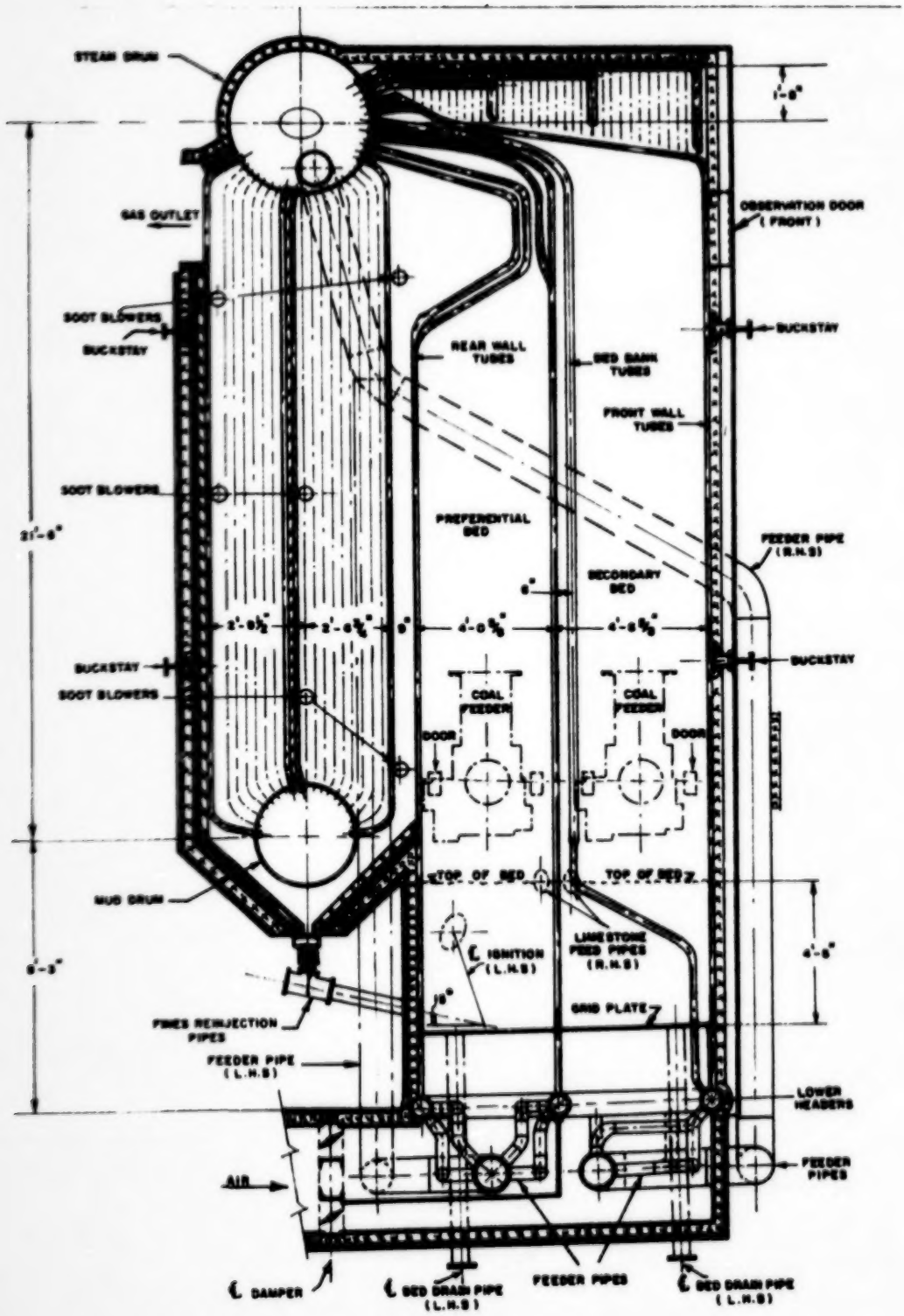


Fig. 1 - Sectional side elevation of the Foster Wheeler boiler design

The fluidized bed consists of two sections arranged side by side parallel to the boiler drums. The bed closest to the drums is called the preferential bed, the other being the secondary bed. Bare membrane walls surround the beds and a membrane wall separates them up to the level of the furnace exit. Thus, the furnace contains virtually no refractory. The preferential bed is intended to be in service whenever the boiler is operating. The secondary bed is brought into service whenever steam demand excees about 40%.

The preferential bed has approximate dimensions of 1.2 m x 2.9 m and contains no heat exchange surface other than the membrane walls which form it. Design operating conditions are a temperature of 885°C, an expanded bed depth of 1.37 m, a superficial fluidizing velocity of 2.44 m/s and an excess air level of 25%. In addition to coal, the preferential bed receives all the wood chips and recycled fly ash fed to the boiler.

The secondary bed is slightly larger, 1.4 m x 2.9 m, and burns 65% of the coal fired at full load. Design operating conditions are a temperature of 830°C, an expanded bed depth of 1.37 m, a superficial fluidizing velocity of 3.05 m/s, and an excess air level of 20%. It incorporates immersed heat transfer surface in the form of eighteen sloped tubes passing through the bed as shown in Figure 1. Like the membrane walls, these are cooled by natural circulation.

Combustion air is introduced through uncooled distributor plates via stainless steel bubble caps which project above the plates and thus leave a few centimetres of unfluidized material to serve as insulation. Each bed section is supplied from a completely separate air plenum.

The furnace cavity is tall, approximately 7 m from the bed surface to the top of the furnace exit. This is expected to accomplish several objectives including completion of combustion and neutralization reactions and heat transfer. From the furnace exit the gases flow through a two-pass convective heat transfer zone. The design boiler exit temperature is 270°C.

Predicted performance data for the boiler are summarized in Table 10.

B Feed Systems for Coal, Wood and Limestone

The Foster Wheeler design meets the requirement for overbed feed of 50 mm x 0 coal by utilizing conventional paddle-wheel spreader feeders.

Table 10 - Predicted performance data for the conceptual boiler designs when operating with the design coal at 100% MCR

		Foster Wheeler Design	Integ-CPC Design
Steam Flow	kg/h	18 000	18 000
Outlet pressure	kPa	965	760-975
Outlet temperature	°C	saturated	160-180
Feedwater temperature	°C	104	n.s.*
Coal feedrate	kg/h	2214	2152(7% moisture)
Limestone feedrate	kg/h	1021	1498
Combustion air flow	kg/h	21 190	n.s.
Total gas side loss	mm H_2O	310	n.s.
Total air side loss	mm H_2O	1455	n.s.
Particulate emissions	mg/MJ	50	50
SO_2 emissions	g/MJ	0.6	0.6
NO_x emissions	g/MJ	0.5	0.5
Boiler efficiency (ASME)	%	81.16	83.0
Stack temperature	°C	170	149
Forced draft fan horsepower		260	n.s.
Induced draft fan horsepower		105	n.s.

*n.s. = not specified

These are located, one per bed section, approximately 0.8 m above the expanded bed level in the boiler side wall. Thus, they throw along the longer bed dimension. Since 50 mm coal is considered too coarse for uniform spreading, the upstream coal handling system incorporates a crusher which reduces the coal size to 25 mm x 0. Control of coal feed rate and distribution using spreader feeders is a well-established technology.

Limestone is introduced into each bed section through a drop pipe which terminates just above the level of the expanded bed, at the end opposite the coal feeder. The bed drains, on the other hand, are located at the coal feeder end. Thus, any limestone which is not elutriated must traverse the length of the bed, which maximizes the residence time available for reaction. The limestone feed rate is controlled by belt-type feeders discharging into the drop pipes.

To feed wood chips to the preferential bed, an overbed pneumatic spreader is proposed. It consists of a chute leading into the furnace, with an array of horizontal air jets along the lower edge. As the chips slide over the edge of the chute they are propelled into the furnace by the air jets. The principle has been successfully applied for many years in wood-fired boilers. It is proposed to build the wood chip feeder and coal feeder as a single unit, with the wood chip chute and air jets located just above the coal chute and the paddlewheel apreader. A belt-type feeder immediately upstream of the wood chip chute controls the wood chip feed rate.

C Carbon Recycle and Bed Drain Systems

To provide an adequate degree of carbon burnout, flue gases leaving the boiler are passed through a bank of mechanical cyclone dust collectors. The fly ash trapped by the cyclones together with that retained in the boiler-bank hopper is then continuously reinjected into the preferential bed a short distance above the air distributor, by means of an array of pneumatically-operated eductors. In addition to improving carbon burn-out, the recycle system is expected to improve limestone utilization.

The bed drain system has the dual function of maintaining the desired bed level in each cell and cooling the drained material to about 150°C. As mentioned previously, the bed drain pipes, one per bed section, are located at the opposite end of the bed from the limestone feed pipes. Drain pipe diameter is 15 cm. To control the rate of material removal, and thus the

bed level, each drain is equipped with a variable-speed rotary valve. Ash discharged from the valves is cooled in a water-jacketed screw conveyor and then conveyed pneumatically to an ash silo.

D Bed Light-up System and Procedure

To light up the boiler it is proposed to use a single light-oil-fired burner having a capacity of 11.4 kW, located at the coal feeder end of the preferential bed, somewhat above the static bed level, and angled downward.

Normal start-up procedure with a cold bed is as follows:

1. Charge each bed cell with calcined limestone to a depth of approximately 0.5 m.
2. After purging the ignitor, fluidize the bed cells separately for 5 min each, then together for 5 min, then slump both beds.
3. Light the ignitor and fire it over the slumped preferential bed for 30 min.
4. With the ignitor still operating, "fluff" the preferential bed by fluidizing for 5 sec. Repeat every 15 min until bed temperature levels off between 150°C and 200°C.
5. Fluidize the bed for 10 min and feed approximately 50 kg of coal, while monitoring O_2 and bed temperature. If temperature rises and O_2 falls, a coal fire is indicated and coal feed is increased. If after 10 min a coal fire is not indicated, slump the bed and repeat Step 4. The ignitor is left on until the bed temperature reaches 800°C.
6. Once the preferential bed is at full operating temperature, the secondary bed is ignited by opening a slide gate in the partition wall. Rapid mixing of the two beds occurs, resulting in ignition of the secondary bed.

E Boiler Control System

The automatic control system proposed for the Foster Wheeler fluidized-bed boiler is fairly conventional. Measurement of steam flow and steam pressure provides the primary signal which controls fuel flow and air

flow to each bed. Trim signals, provided by measurement of fuel flow, air flow, bed temperature and oxygen in the flue gas, act to maintain bed temperatures within the desired limits, and to maintain excess air at 25% in the preferential bed, and 20% in the secondary bed. To avoid frequent start-up and shut-down of the secondary bed when steam demand fluctuates about 40% of boiler capacity, some overlap in the steam-generating capacity of each bed is required. This is accomplished by varying both bed temperature and bed level within limits.

Limestone feed to each bed section is controlled primarily by fuel flow to that section but is trimmed according to measurement of SO_2 in the freeboard above that section. Rate of flow through the bed drain is controlled primarily by bed level, as measured by pressure drop across the bed, with a trim signal provided by the limestone feed rate.

Other boiler control functions, such as feed water flow and furnace draft, are achieved by conventional technology.

F Secondary Heat Recovery and Flue Gas Clean-up

To meet the design requirement for a maximum stack temperature of 175°C, an economizer is located downstream from the mechanical cyclone dust collector. This is of a finned tube design with a nominal surface area of 123 m^2. The economizer is equipped with a single sootblower.

Final gas clean-up with respect to particulates is accomplished by means of a bag filter. As it is located downstream from the mechanical cyclones and economizer, it needs only contend with relatively cool flue gas laden with fine particulates. Teflon-coated felt bags are proposed, with an air-to-cloth ratio of 0.97 m^3/min per m^2 of cloth when all cells are active, and 1.06 m^3/min per m^2 of cloth when one cell is in the cleaning cycle. The pressure drop through the bag filter is expected to lie between 100 mm and 150 mm H_2O.

THE INTEG-CPC DESIGN

A Boiler and Combustion Chamber

The Integ-CPC conceptual design is based upon a bottom-supported two drum watertube steam generator utilizing natural circulation in the furnace walls and convection banks, but forced circulation for the heat exchange

surface immersed in the fluidized bed. A sectional side view and plan are shown in Figure 2. Approximate dimensions are: height = 7.5 m, width = 5.1 m, depth = 5.0 m. The designer stated that these dimensions could be reduced if it were not for a contract requirement that it be possible to retrofit a coal stoker to the boiler.

The fluidized bed consists of four identical sections, approximately 0.77 m wide x 2.6 m long arranged side by side at right angles to the drums. As can be seen from Figure 2, the bed sections have refractory walls extending approximately 3 m above the level of the distributor plate. This is intended to promote freeboard combustion, thus reducing carbon carryover and improving fuel flexibility. All bed sections can operate independently of one another. Nominal bed conditions are a temperature of 850°C, an expanded depth of approximately 1 m,and an excess air level of 20% when burning coal only, but 30% when burning coal and wood.

The radiant furnace section is located above the refractory bed section and is of membrane-wall construction. It, together with the two-pass convective heat transfer section, employs natural circulation. A full complement of sootblowers is provided. Each bed section is cooled by a number of horizontally-oriented single hairpin tubes which are tied into the boiler circuitry, but through a forced circulation system.

Since the bed sections are capable of operating independently, each has a separate air plenum under the distributor plate. The distributor plate is of a proven, proprietary design.

Some predicted performance data for the boiler are given in Table 10.

B Feed Systems for Coal, Wood and Limestone

In the Integ-CPC design, coal and limestone bunkers are paired, with one set for each bed section. Under each coal bunker is a variable-speed screw conveyor which expands in cross-section as it passes under the corresponding limestone bunker. As the screw conveyor moves coal at the desired rate, a variable-speed rotary valve under the limestone bunker adds the required quantity of limestone. The two materials are mixed in the expanded portion of the screw conveyor, then drop into a water-jacketed screw conveyor which injects the mixture through the refractory combustor wall just above the expanded bed level. The injection point is near the

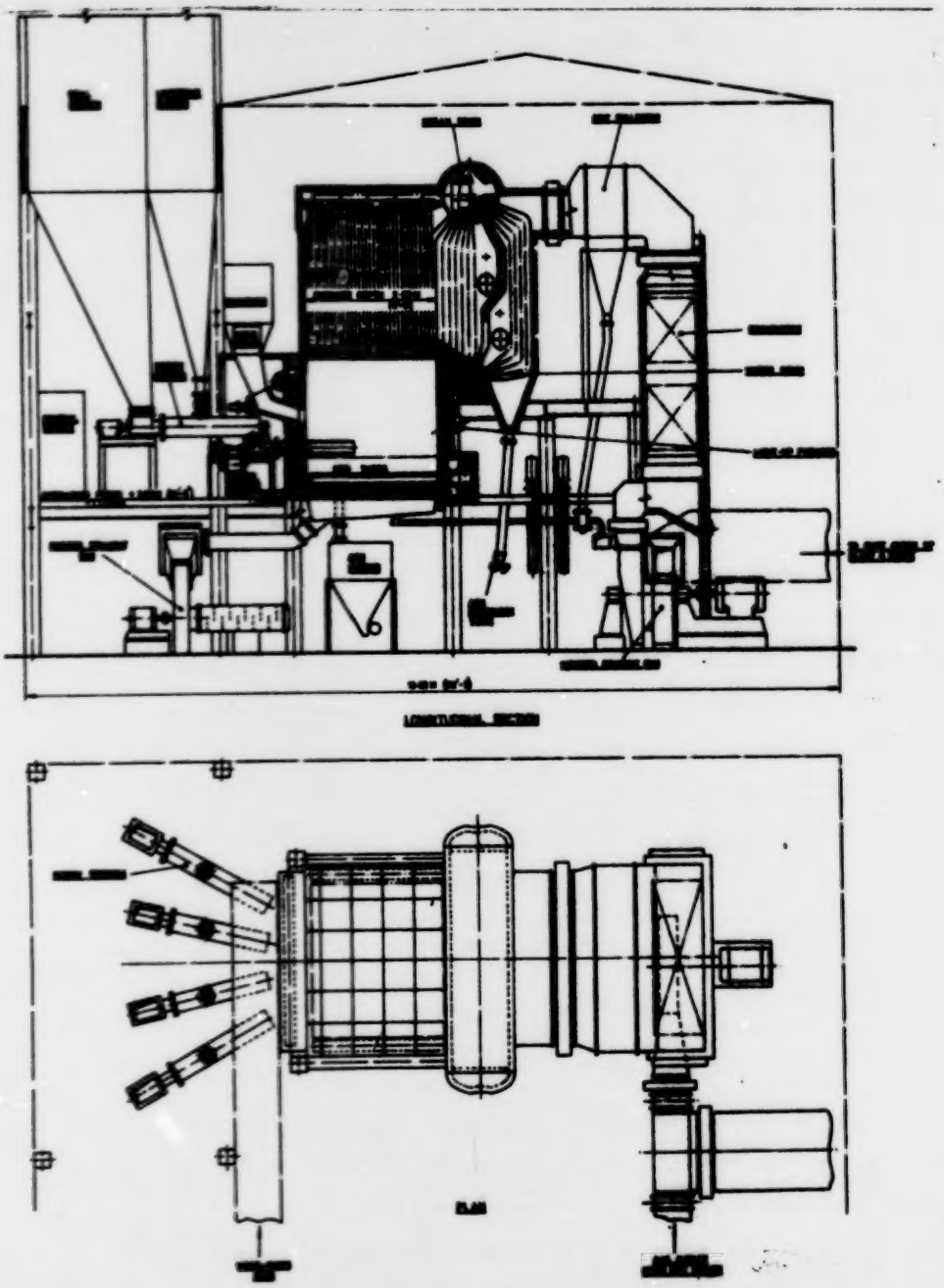


Fig. 2 - Sectional and plan views of the Integ-CPC boiler design

midpoint of the bed section. The feed arrangement is shown clearly in Figure 2. It has the advantage of being able to feed 50 mm x 0 coal without further preparation and with minimum elutriation of fines.

The wood chip feed system begins at an external storage hopper from which the wood chips are extracted by variable-speed travelling screw feeders. These control the rate of feed. A belt conveyor then transports the chips to small hoppers at the front of the boiler, one for each bed section. Each hopper has a chute discharging into the bed through the refractory wall. Air nozzles under the chute distribute the wood chips over the length of the bed. It is intended that the feed rate of chips be varied stepwise, according to the number of bed sections in service, rather than continuously according to steam demand.

C Carbon Recycle and Bed Drain Systems

The Integ-CPC design also addresses the matter of carbon recycle by placing a mechanical cyclone dust collector downstream from the boiler and providing for reinjection of the fly ash thus trapped back into the fluidized bed, along with fly ash from the boiler convection bank. A pneumatic injector is located in the bottom of each bed section. Transport air is supplied by the forced draft fan and interlocks are provided to ensure that fly ash is only injected into active bed sections. There are also provisions to direct the fly ash to the ash silo if recycle is not required.

Each bed section has a single drain through which the bed section is drained, or spent bed material is withdrawn. Each drain is equipped with a knife gate valve or a rotary valve to control the discharge rate as required to maintain bed level. The valves in turn discharge into an ash cooler, from which the spent bed material flows into a small intermediate storage hopper. It is then transported pneumatically to a large ash silo.

D Bed Light-up System and Procedure

The light-up system for the boiler is based on the system developed and proven at the Renfrew demonstration facility of Babcock and Wilcox (UK). Each of the four bed sections has a retractable light-oil-fired burner located in a tunnel in the rear refractory wall, above the expanded bed level, angled to fire downward onto the bed. The boiler is brought into service by lighting up one bed section at a time. This is done by fluidizing the selected section and operating its burner until the bed temperature reaches approximately 650°C.

Coal feed is then started, whereupon the bed temperature rises rapidly. When it reaches 850°C, the oil burner is turned off, and the procedure is repeated with the next bed section. Light-up is a semi-automatic operation, with the operator selecting the bed to be fired and starting the main electrical drives, and the control system sequencing subsequent procedures.

E Boiler Control System

A sophisticated system of automatic controls, based on electronic instrumentation and a microprocessor computer, is a significant feature of the Integ-CPC design. The basic objective is to enable one operator to supervise all the boiler functions from one control panel.

A steam pressure controller provides a load demand signal which is fed to identical combustion controls on each of the four bed sections. Operating conditions, i.e., feedrate, air rate, bed level and bed temperature are identical for all bed sections that are fluidized. Turndown is achieved by varying bed temperature within limits. For example, at full load all four sections are in operation and near the upper temperature limit. As load drops, feedrate is reduced to all bed sections, and bed temperature drops. When the lower limit is reached the operator is so advised. He then slumps one bed, the control system increases the feed rate to the remaining three sections, and bed temperature rises correspondingly. There is sufficient overlap in capacity between, for example, three beds at maximum temperature and four beds at minimum temperature, to prevent minor fluctuations in load from causing frequent slumping and reactivation of a bed section.

Air flow and limestone feedrate are controlled according to coal feedrate, with each bed section having independent measuring systems. An SO_2 analyzer sampling the flue gas provides the operator with guidance to manually bias the coal/limestone ratio. Excess air level is normally held constant over the load range, but it can be manually biased by the operator.

Bed drain valves are operated to maintain the bed level in each section within the desired limits. Bed levels are determined from windbox pressure, with a correction for air flow rate.

Conventional technology is applied to the other boiler control functions.

F Secondary Heat Recovery and Flue Gas Clean-up

An economizer designed to provide a full-load gas outlet temperature of 150°C is located downstream from the mechanical cyclone dust collector. It is a cross counterflow unit comprising two banks of finned tubes, fabricated in carbon steel.

A bag filter constitutes the means of final particulate clean-up. It is located downstream from the economizer and is of a modular design, each section having a hopper and rotary valve through which the collected dust may be withdrawn, and then transported penumatically to the ash silo.

SUMMARY

A number of FBC boilers, ranging up to 45,000 kg/h in steam capacity, are operating successfully in the United States and Great Britain. However, to the best of the author's knowledge, none of them face as severe a challenge in terms of fuel quality as the combination of wood chips and wet, poorly sized, high-sulphur, high-ash coal specified for the CFB Summerside project. Two teams of designers have responded with what seem to be eminently practical but substantially different designs to meet the specified capacity of 18,000 kg/h.

The Foster Wheeler design, based upon American technology, proposes two bed sections of unequal size, both contained by water-cooled membrane walls, with coal feed over the beds by paddlewheel spreaders, and wood chips fed by means of a pneumatic spreader. The smaller bed is always in service and receives all the wood chips as well as all the recycled fly ash. It contains no immersed heat exchange surface. The larger bed takes up load demand in excess of 40% of MCR, burns only coal, and has an inclined bank of steam generating tubes passing through the bed. Limestone is fed onto each bed surface by a simple drop-pipe arrangement. Natural circulation is employed throughout.

The Integ-CPC design, based upon British technology,proposes four equal bed sections contained by refractory walls. Coal and wood chips are fed over the bed by means of water-cooled screw conveyors and pneumatic spreaders, respectively. Fly ash is recycled to each bed by pneumatic in-bed injectors. Limestone is dosed into the coal feed screw conveyors. Immersed in each bed section is a horizontal bank of heat exchange tubes, cooled by

forced circulation. The remainder of the boiler circuit employs natural circulation.

The Foster Wheeler design concept has now been successfully demonstrated at Georgetown University in Washington, D.C. All aspects of the Integ-CPC design, except for the use of water-cooled screw conveyors for overbed coal feed, have been successfully demonstrated in installations such as B & W's Renfrew works, Antler Luggage at Bury, and Rist Wire and Cable at Newcastle-under-Lyme.

Both designs are now being finalized, together with detailed design and price proposals for the entire plant. Contract award is scheduled for March 1981, and the sponsors of the project look forward to successful commissioning of Canada's first fluidized-bed boiler about January 1983.

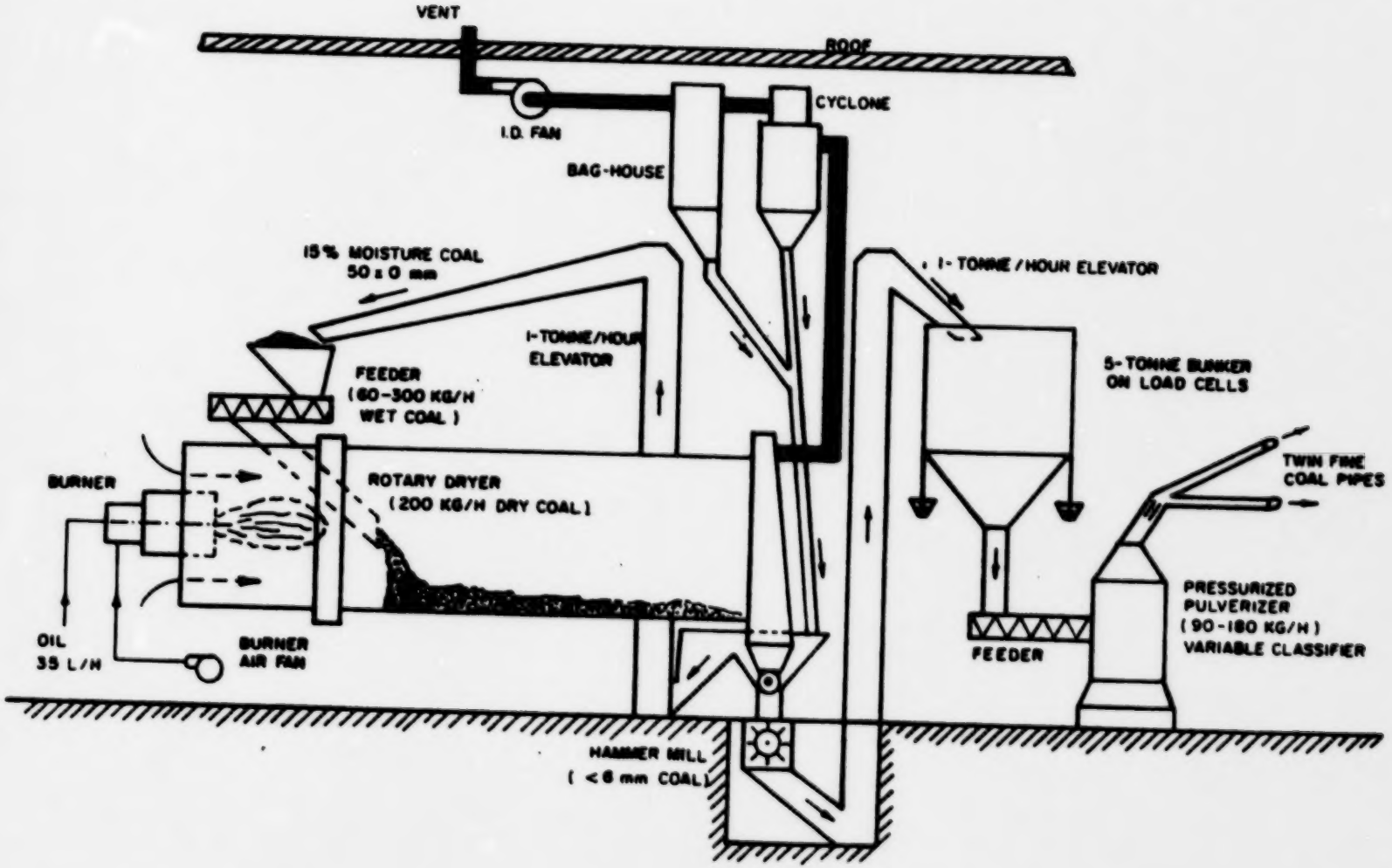


Fig. 4 - Schematic illustration of solid fuel drying and grinding system

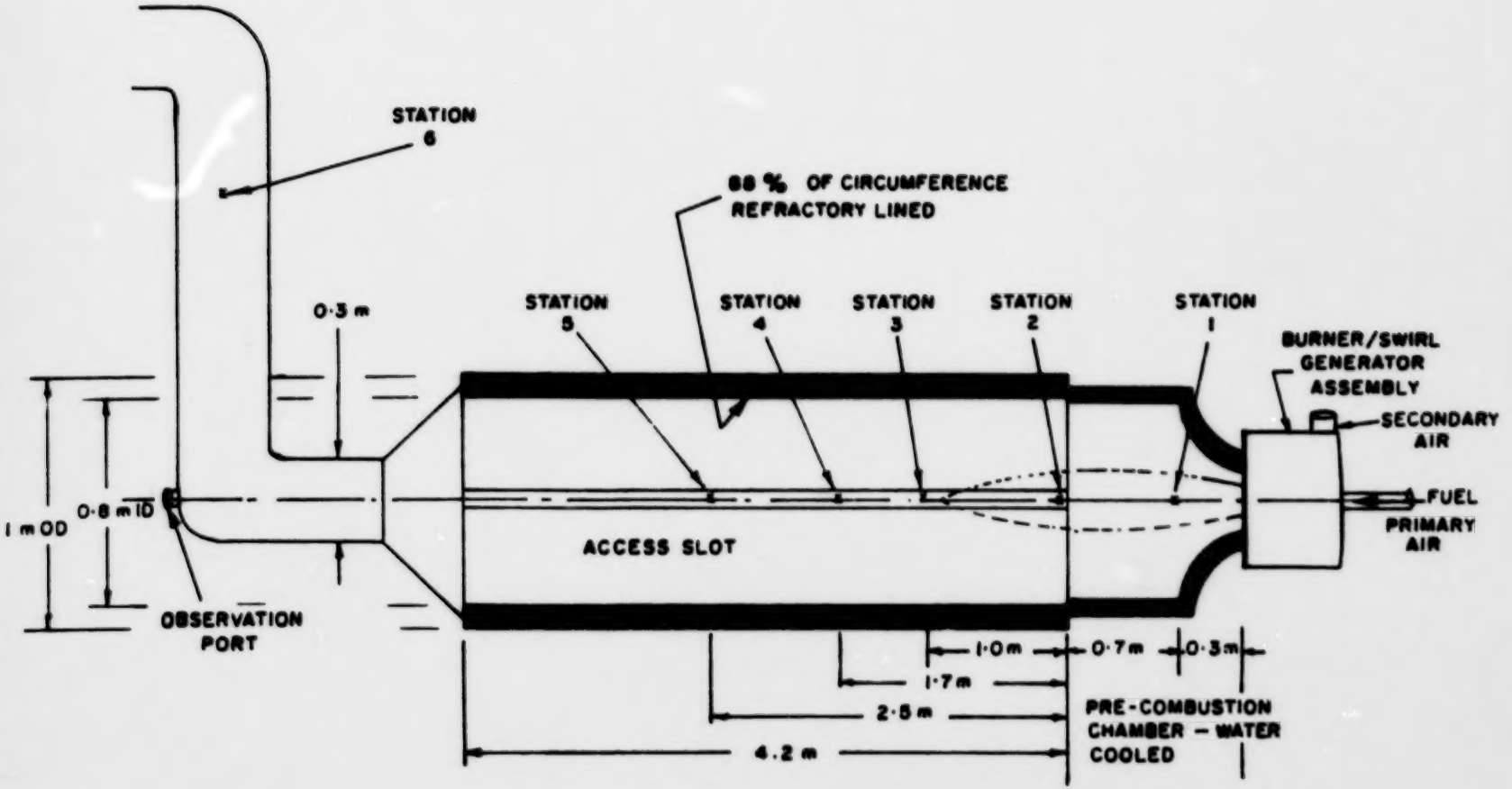
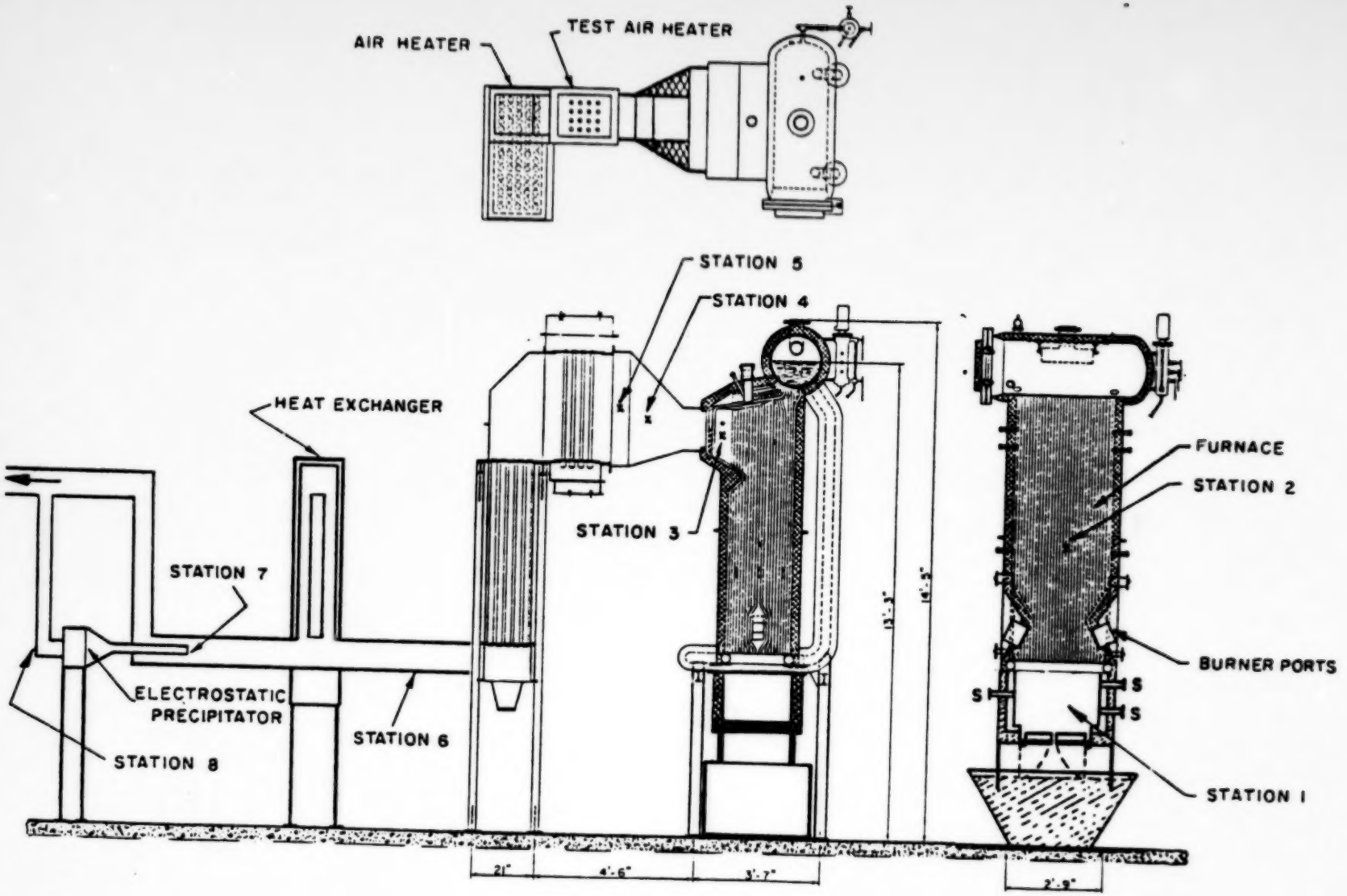


Figure · Schematic view of the CCRL Flame Tunnel Furnace.


AIR HEATER
TEST AIR HEATER
STATION 5
STATION 4
HEAT EXCHANGER
STATION 3
STATION 7
ELECTROSTATIC PRECIPITATOR
STATION 6
STATION 8
FURNACE
STATION 2
BURNER PORTS
S
S
S
STATION 1
21"
4'-6"
3'-7"
2'-9"